Membrane Processes for Direct Potable Reuse in Long-Term Space Missions

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Water and Wastewater in Space

- Fresh water supply:
  - Short missions – full supply taken from earth
  - International Space Station (ISS) – periodic resupply (no reuse)
  - Long-range, long-duration – MUST RECYCLE AND REUSE

- Without careful recycling, 40,000 pounds of water from Earth would be required to resupply a minimum of four crewmembers per year

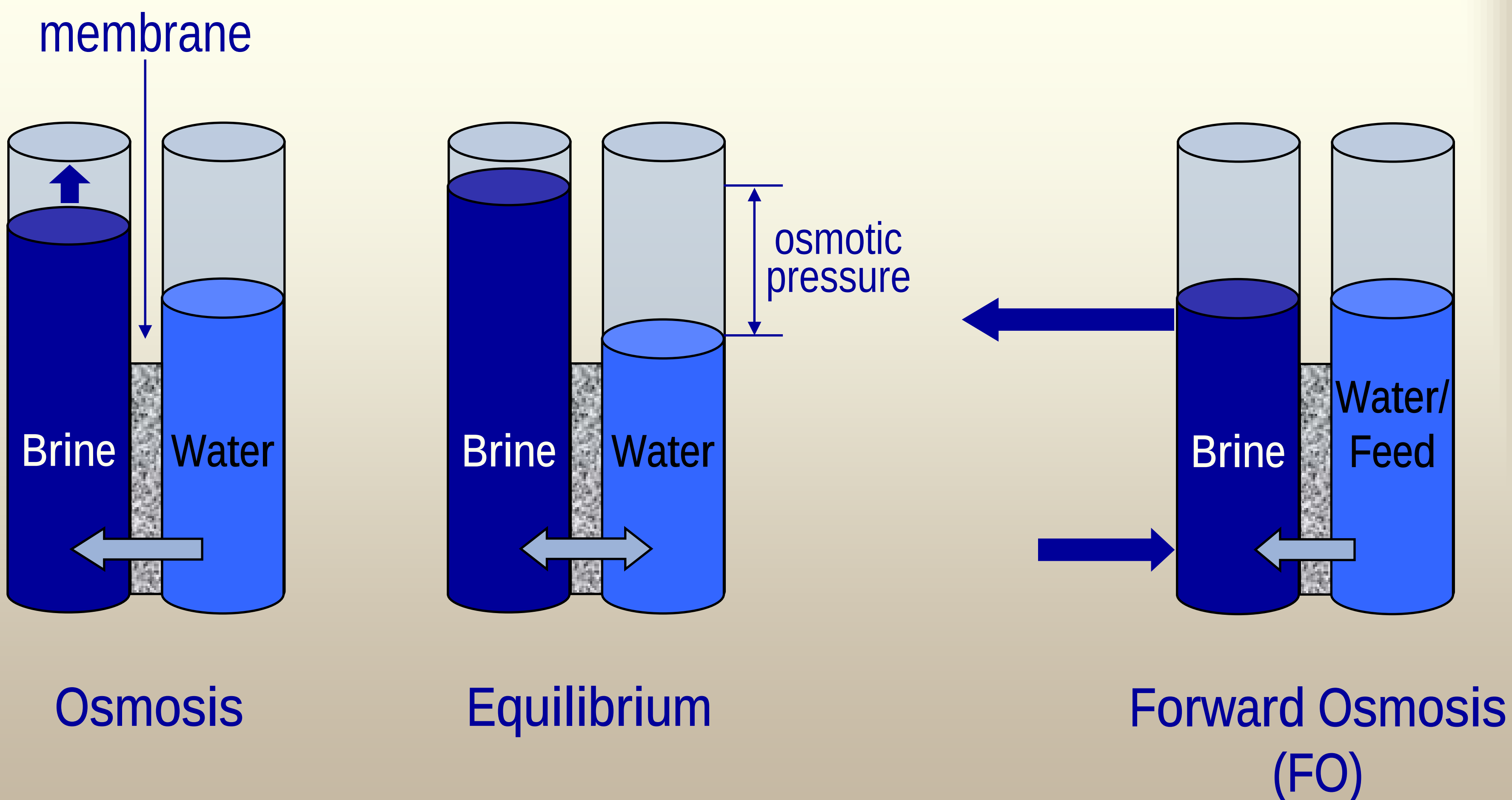
Space Water Recycling System

- needs to reclaim wastewater from several sources, including:
  - Hygiene (~25 l/person/day)
  - Humidity condensed from the air (~1.8 l/person/day)
  - Urine (~2 l/person/day)
- needs to:
  - be reliable, durable, redundant, capable of high recoveries, economical, and lightweight
  - operate autonomically with low maintenance
  - have minimal consumables

Membrane Processes
and specifically, the reverse osmosis process

- Advantages:
  - High rejection, durability, small footprint, simple operation, minimal resupply of consumables
- Disadvantages:
  - Susceptible to fouling by dissolved and particulate materials
  - Allows the passage of small molecules such as urea and endocrine disrupting compounds
- Must be used in combination with other processes (e.g., the forward osmosis process)

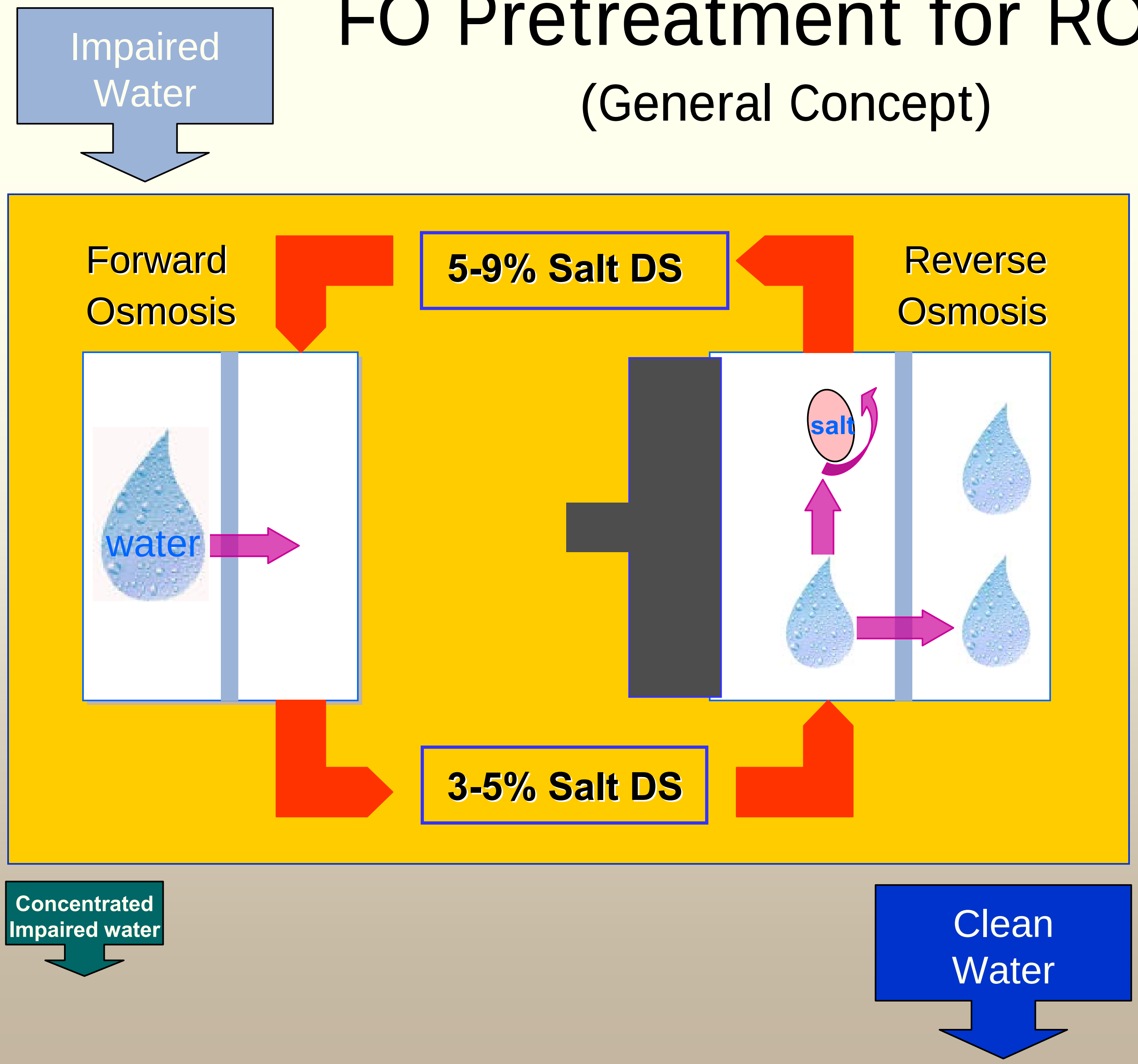
Osmosis and Forward Osmosis



Brine ≡ Draw Solution (DS)

FO Pretreatment for RO

(General Concept)



Forward Osmosis (FO)

Membrane: Dense, semi-permeable, non-porous

Membrane material: Hydrophilic, RO-type membrane

e.g., CTA, CA, PA

Mass transfer governed by: Diffusion

Driving force: Osmotic pressure gradient

Driving force induced by: Concentration gradient

Application: Extraction of water

Original Direct Osmotic Concentration Concept

NASA Direct Osmotic Concentration Test Unit

UNR Objectives

- Short term objectives and tasks:
  - Restoration of DOC subsystems
  - Analysis of mass and heat transfer in DOC subsystems
  - Analysis of alternative membranes
  - Minimization of power consumption
- Evaluate system performance parameters
- Recommend improvements to the system

Comparison of System Performance

	ISS Water Recycling System	Bio-Reactor	VPCAR	Direct Osmotic Concentration System
Re-supply	413 kg/year	119 kg/year	0 kg/year	?
# of Independent Processors	4	6	2	3
Feed Streams	2	1	1	2
Weight	193 kg	396 kg	68 kg	163 kg
Volume	1.1 m^3	1.9 m^3	0.39 m^3	0.78 m^3
Total subsystem power	61.5 Whr/kg	1108 Whr/kg	311.7 Whr/kg	?
Recovery Rate	99%	85-100%	97%	?
Scheduled Maintenance	every 50 days	Unknown	0	?

Test Unit Subsystems

The original DOC test unit consisted of two pretreatment stages and a core reverse osmosis array

- DOC#1 utilized a forward osmosis process only
- DOC#2 utilized a unique combination of forward osmosis and osmotic distillation (dual FO/OD process) to assist in rejecting small compounds, like urea, that easily diffuse through semi-permeable membranes
- Reverse osmosis subsystem utilized 5 RO elements to produce purified water and draw solution

Osmotic Distillation (OD)

Membrane: Microporous

Membrane material: Hydrophobic

e.g., Polypropylene, PTFE, PVDF

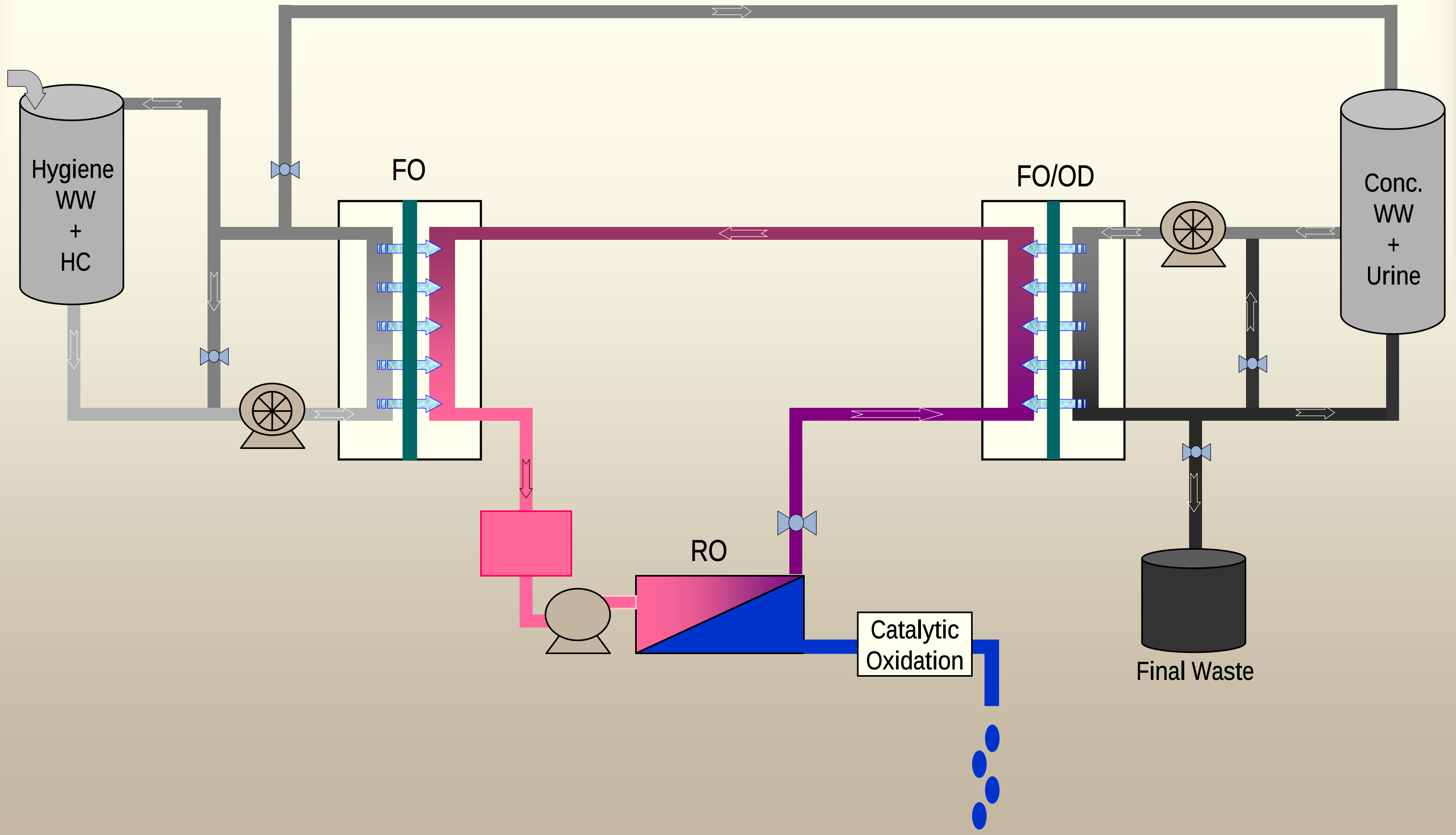
Mass transfer governed by: Evaporation through pores

Driving force: Partial vapor pressure grad.

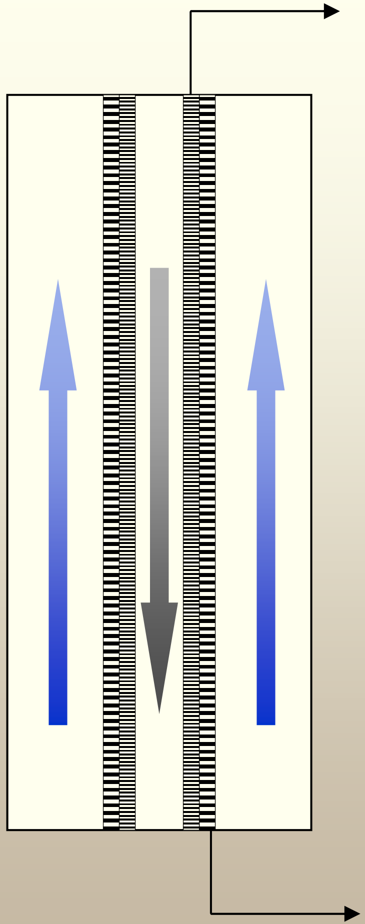
Driving force induced by: Concentration gradient

Applications: Concentration of non-volatiles

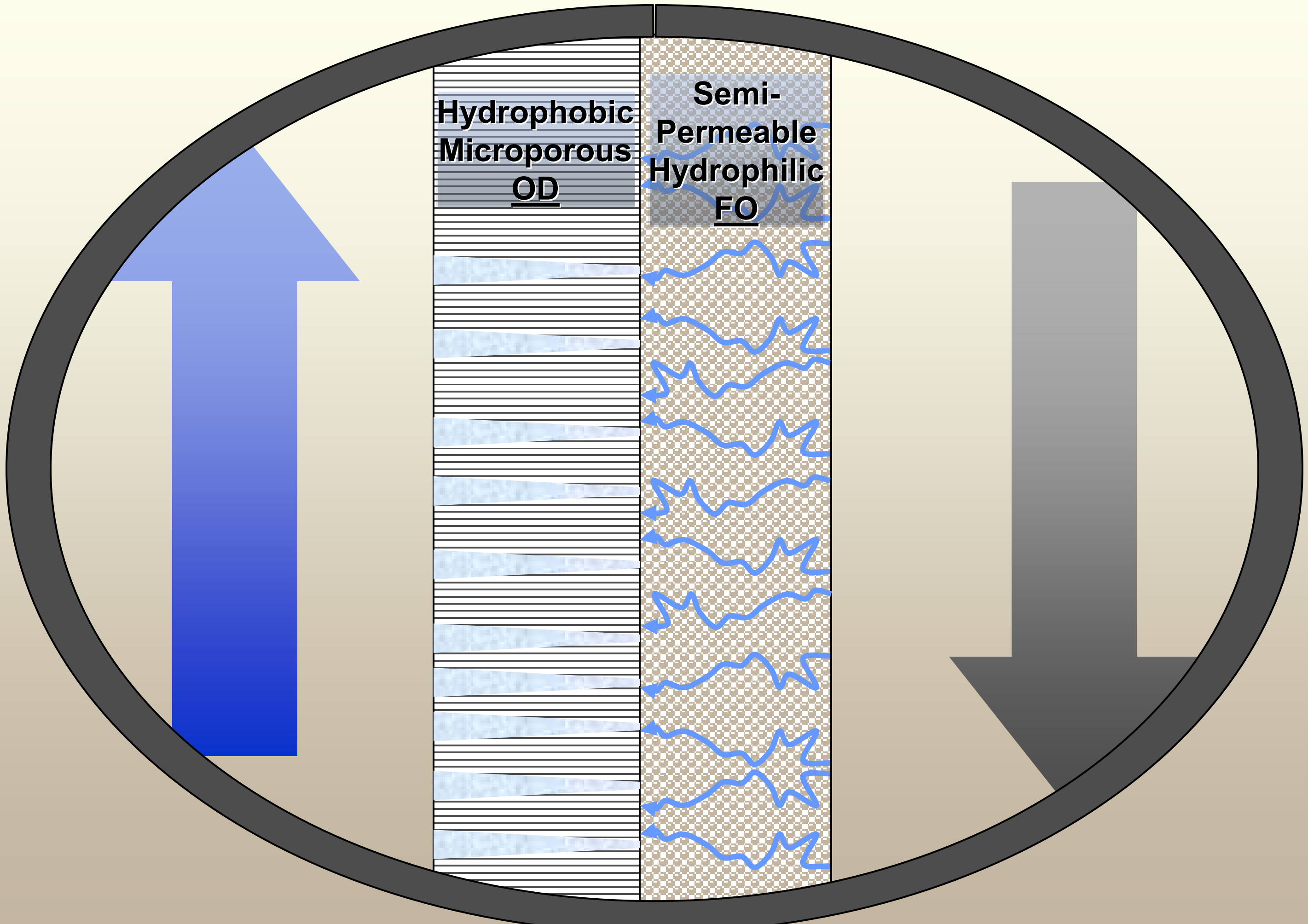
Schematic of Original DOC Test Unit



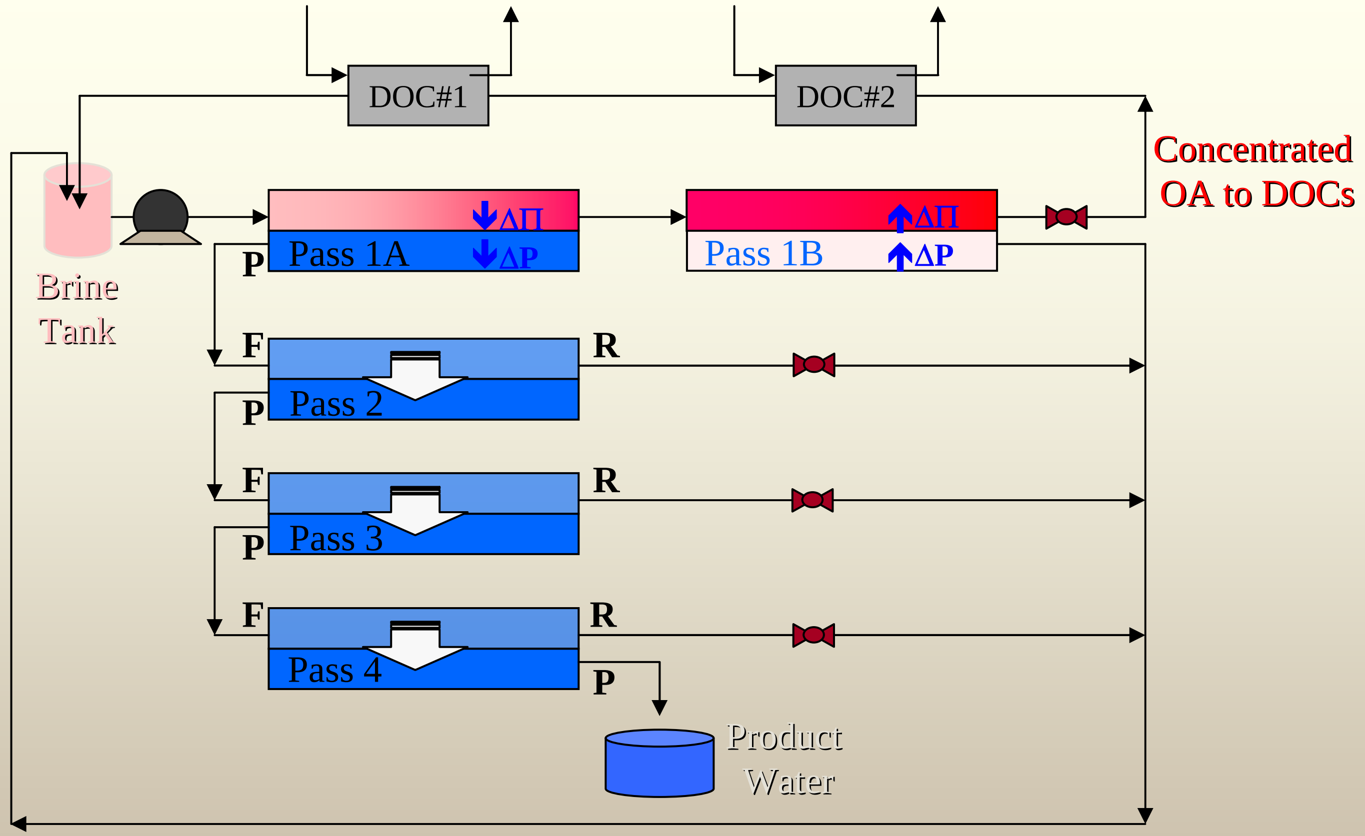
FO/OD – Dual-Membrane Contactor



DOC#2 – Dual-Membrane Contactor



The RO Subsystem



Comparison of System Performance

	ISS Water Recycling System	Bio-Reactor	VPCAR	Direct Osmotic Concentration System
Re-supply	413 kg/year	119 kg/year	0 kg/year	~20 kg/year
# of Independent Processors	4	6	2	3
Feed Streams	2	1	1	2
Weight	193 kg	396 kg	68 kg	163 kg
Volume	1.1 m^3	1.9 m^3	0.39 m^3	0.78 m^3
Total subsystem power	61.5 Whr/kg	1108 Whr/kg	311.7 Whr/kg	20-30 Wh/kg
Recovery Rate	99%	85-100%	97%	> 92%
Scheduled Maintenance	every 50 days	Unknown	0	Unknown

Major Issue: Low Mass Transport in DOC#2

- Low mass transport in DOC#2 subsystem
  - Low flux and recovery (was designed to recover approximately 10% of the wastewater; practically recover less than 2%)
  - Flooding of osmotic distillation membrane resulting in passage of urea
- Potential solution: replace dual forward osmosis/osmotic distillation (FO/OD) process with membrane distillation

Membrane Distillation (MD)

Membrane: Microporous

Membrane material: Hydrophobic

e.g., Polypropylene, PTFE, PVDF

Mass transfer governed by: Evaporation through pores

Driving force: Vapor pressure gradient

Driving force induced by: Temperature gradient

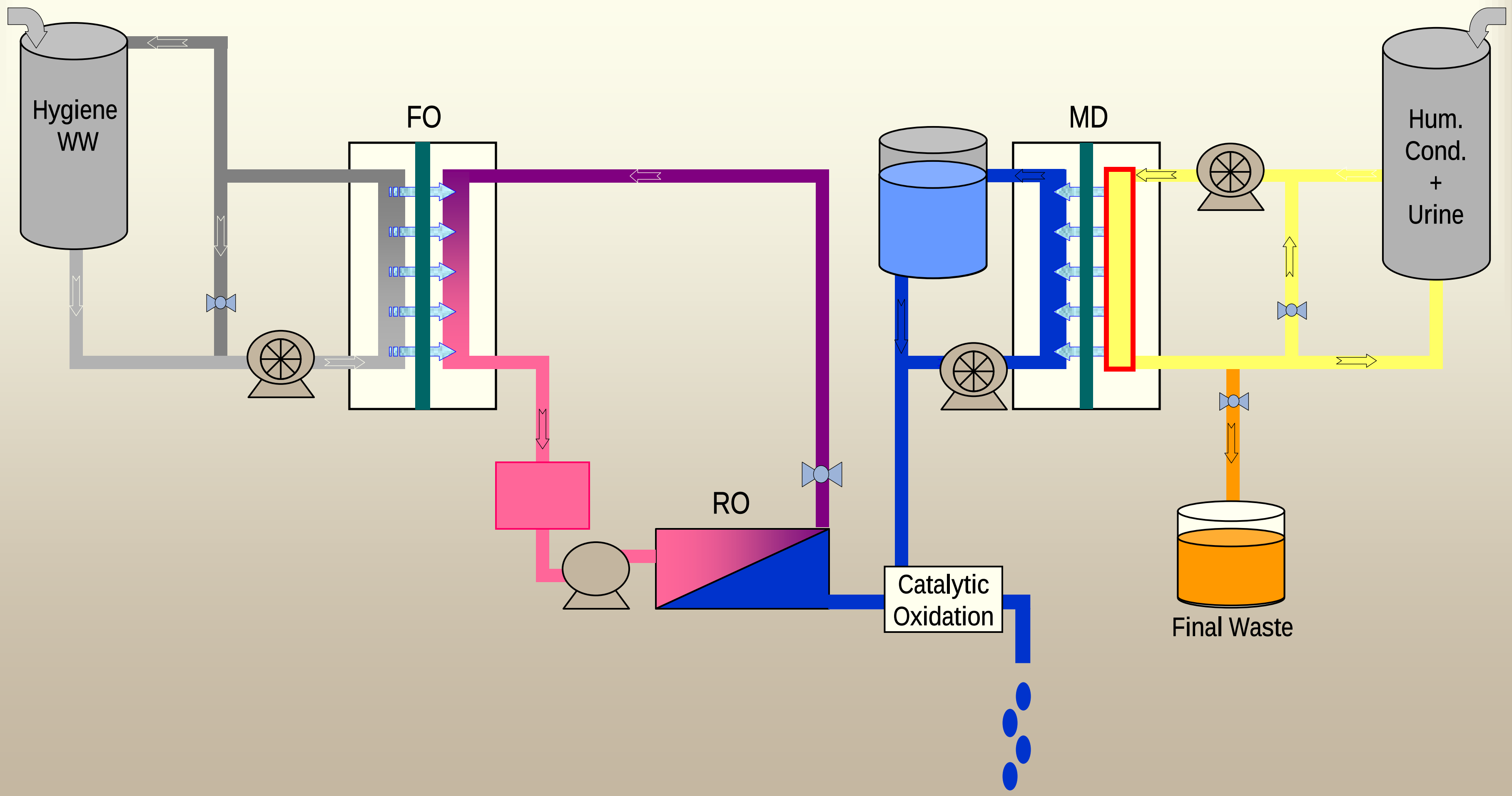
Applications: Removal of water from non-volatiles or VOCs from water

Membrane Distillation

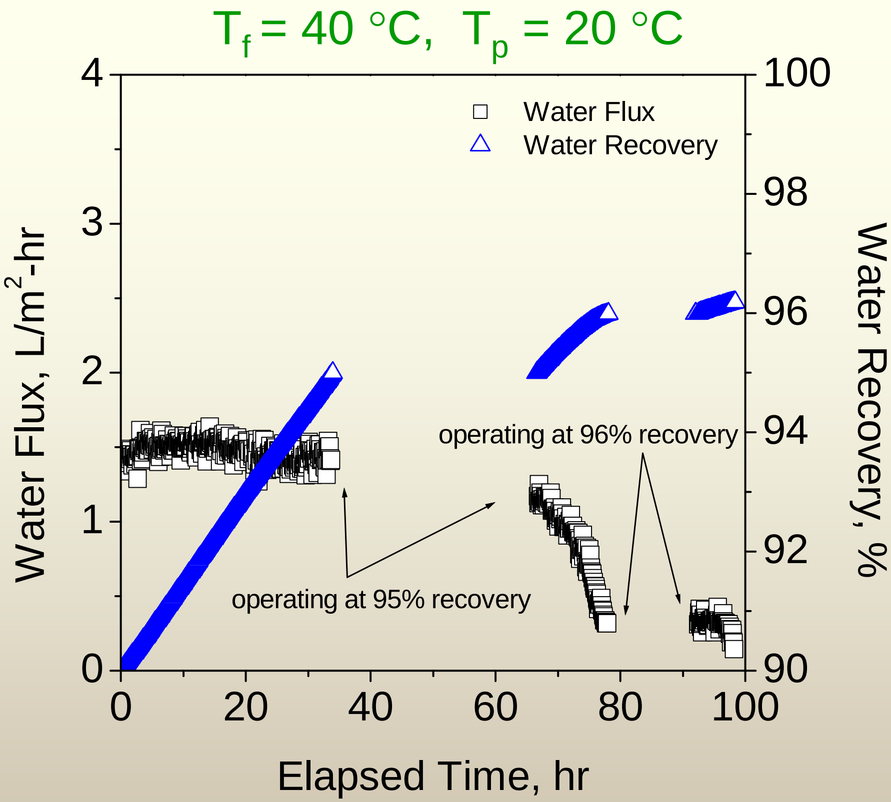
- Compared to distillation, requires only small temperature differences
  Can use low-grade energy/waste heat sources
- Compared to reverse osmosis, does not allow the passage of small non-volatile molecules
  Can provide removal of urea and endocrine-disrupting
- Compared to osmotic distillation, has much higher driving force for mass transfer
  Will produce higher fluxes

Improved DOC Concept

FO/MD Potable Reuse Test Unit



MD for Urea Removal

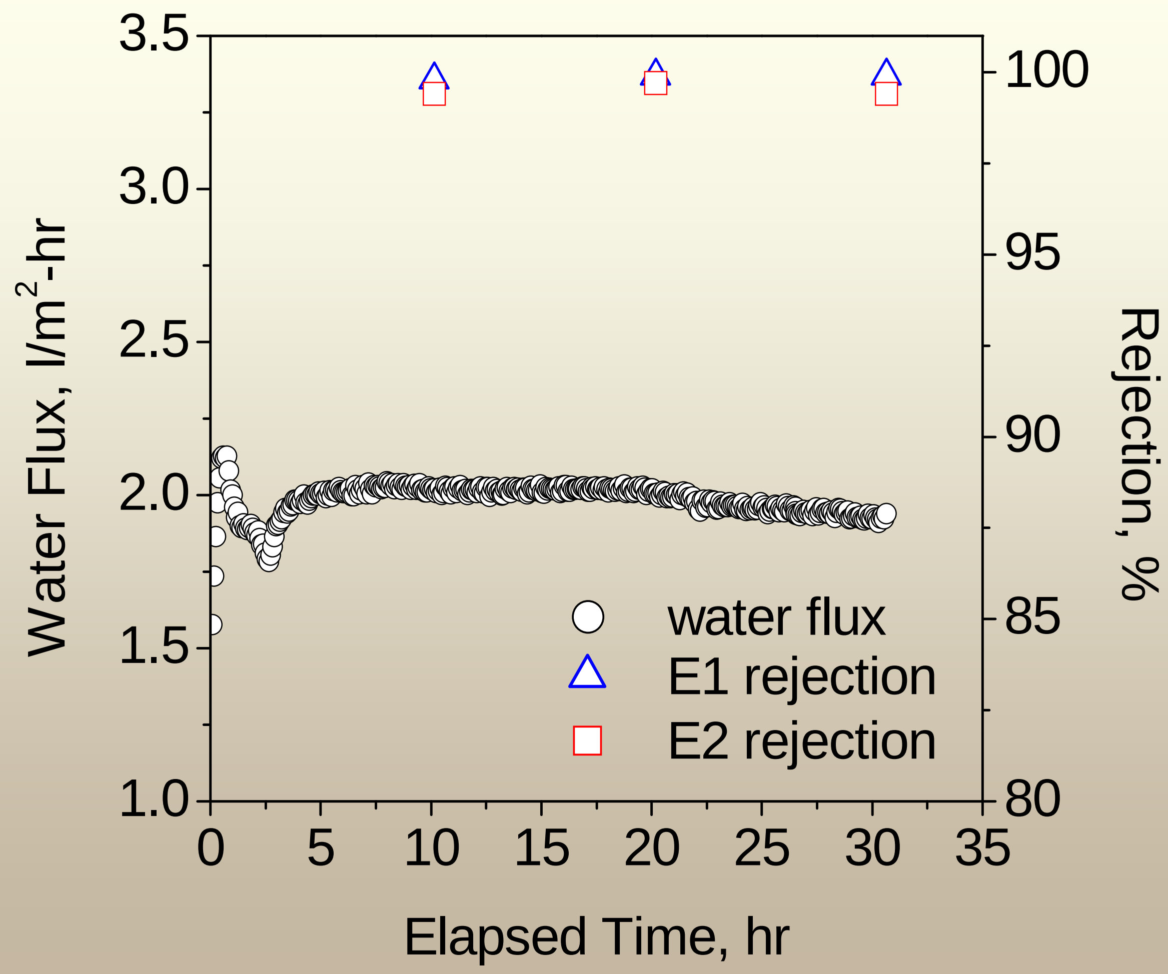


Sample	Water Recovery %	Rejection, %	
		Urea	Ammonia
1	50	>99.9	>99.9
2	90	>99.9	>99.9
3	95	>99.9	>99.9

EDC Removal for Potable Reuse

- During long-term space missions, crew members will consume water that is continuously recycled
- Trace contaminants, and particularly endocrine-disrupting chemicals (EDCs), must be removed
- Removal of estrone and estradiol were evaluated at bench-scale

EDC Rejection by MD



Where is the Technology Now?

- undergoing long-term testing at NASA ARC
- going into "competition" in 2008
  - competing against 3 distillation processes

Acknowledgements

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